T.R.

GEBZE TECHNICAL UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF COMPUTER ENGINEERING

SEM IMAGE ANALYSIS

AYŞE GÜL DEMIRBILEK

SUPERVISOR
PROF. YUSUF SINAN AKGÜL

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GEBZE TECHNICAL UNIVERSITY	GRADUATION PROJECT JURY APPROVAL FORM

This study has been accepted as an Undergraduate Graduation Project in the Department of Computer Engineering in 2023 by the following jury.

JURY

Member
(Supervisor) : Prof. Yusuf Sinan Akgül

Member : Assoc. Prof. Dr. Neslihan Tamsü

ABSTRACT

This research project presents a comprehensive analysis of Scanning Electron Microscopy (SEM) images utilizing deep learning for pore detection.The primary objective is to assess the performance of YOLOv8x in accurately detecting and characterizing pores within SEM images, complemented by the development of an interactive user interface (UI) result interpretation.This research project incorporates a comprehensive analysis of the detected pores based on the geometric characteristics, as outlined in the thesis of Associate Professor Neslihan Tamgü.Furthermore, to enhance the accessibility and user experience, a user-friendly graphical interface has been developed.

Keywords: SEM, YOLO.

ÖZET

Bu araştırma projesi, Taramalı Elektron Mikroskobu (SEM) görüntülerinde gözenek tespiti için derin öğrenmeyi kullanan kapsamlı bir analiz sunmaktadır.Temel amaç, etkileşimli bir kullanıcı arayüzü ile desteklenen YOLOv8x'in performansını değerlendirerek, SEM görüntülerindeki gözenekleri doğru bir şekilde tespit etmek ve karakterize etmektir. Bu araştırma projesi, Doçent Neslihan Tamgü'nün tezinde özetlendiği gibi, tespit edilen gözeneklerin geometrik özelliklerine dayalı kapsamlı bir analizi içermektedir. Ayrıca, erişilebilirliği ve kullanıcı deneyimini artırmak amacıyla kullanıcı dostu bir grafiksel arayüz geliştirilmiştir.

Anahtar Kelimeler: SEM, YOLO.

ACKNOWLEDGEMENT

I appreciate my advisors for their valuable guidance and information. Thank you.

Ayşe Gül Demirbilek

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol / Abbreviation	**Explanation**
SEM	Scanning Electron Microscopy
Precision-Recall (PR) Curve	An essential visualization in classification problems that demonstrates the trade-offs between precision and recall at various thresholds.
F1 Score Curve	Visualizes the F1 score across different thresholds, offering insights into the model's ability to balance false positives and negatives.
Confusion Matrix	A detailed matrix that presents counts of true positives, true negatives, false positives, and false negatives for each class, providing a comprehensive view of classification outcomes.
P (Precision)	The proportion of detected objects that are actually correct, indicating accuracy in object detection.
R (Recall)	The proportion of actual objects that are successfully identified by the model, reflecting its ability to detect all instances of objects.
mAP50	Mean average precision calculated at an intersection over union (IoU) threshold of 0.50, representing model accuracy for "easy" detections.
mAP50-95	The average of mean average precision computed at varying IoU thresholds ranging from 0.50 to 0.95, providing a comprehensive assessment of model performance across different levels of detection difficulty.

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1. DATASET

With guidance from advisors, a curated selection of 500 Scanning Electron Microscopy (SEM) images was obtained, from which 300 images containing discernible pores were identified for further analysis. The annotation process was conducted with precision and detail, involving the labeling of 23,460 pores through bounding boxes utilizing the Roboflow annotation tool. [1]

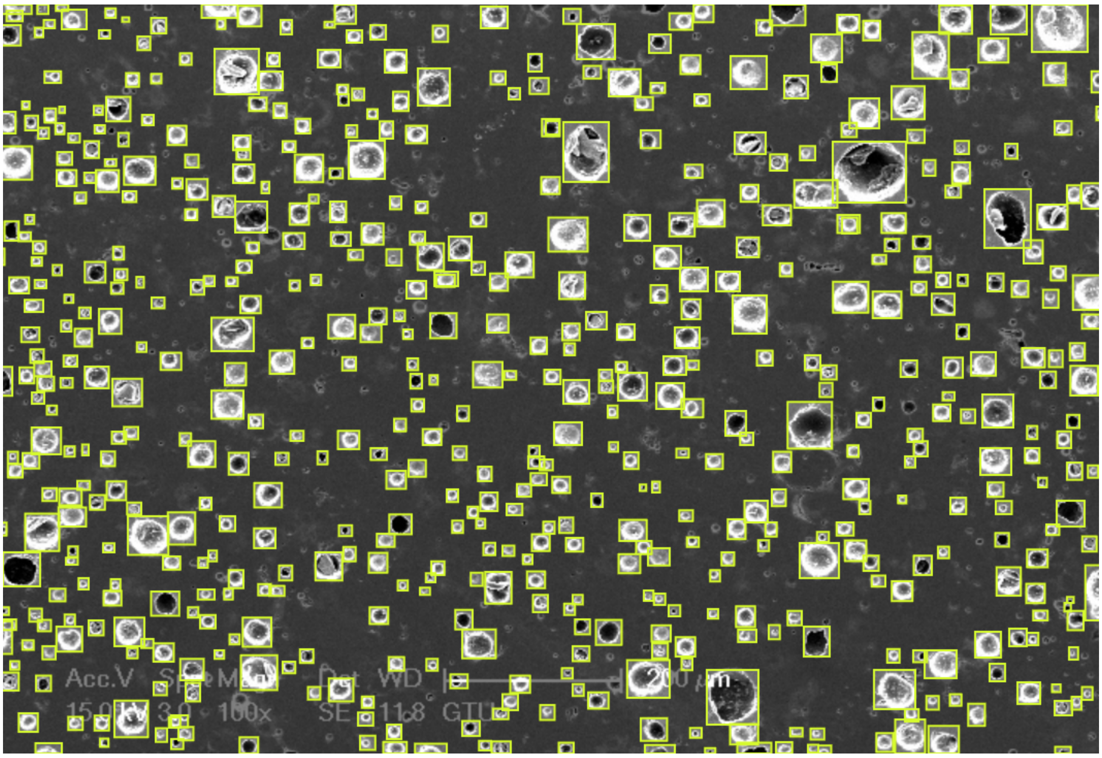

Figure 1.1: Image with approximately 500 pores.

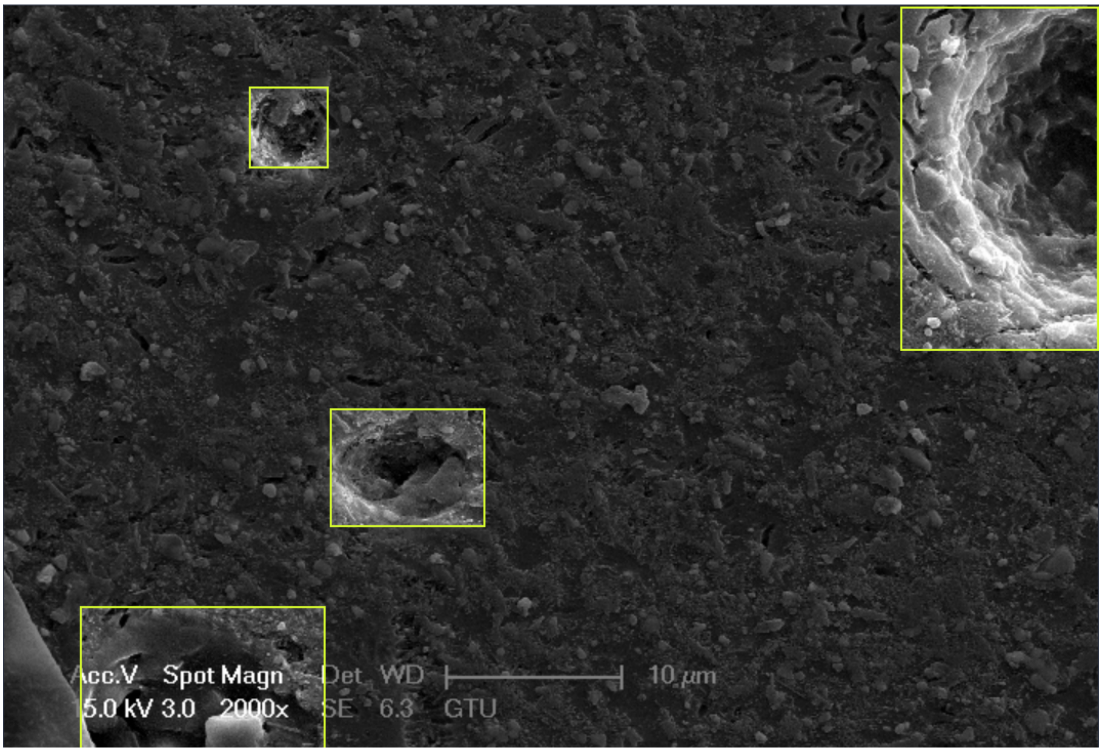

Figure 1.2: Image with only 4 pores.

1.1. Exportation of the Dataset

Roboflow's annotation style allowed for the accurate delineation of pore locations within the SEM images, providing the necessary ground truth labels for subsequent model training. To facilitate seamless integration with the YOLOv8x model, the annotated dataset was exported in YOLO format. This format ensures compatibility with the model's training requirements, with each annotated pore represented by its bounding box coordinates. [2]

1.2. Histogram of Object Count by Image

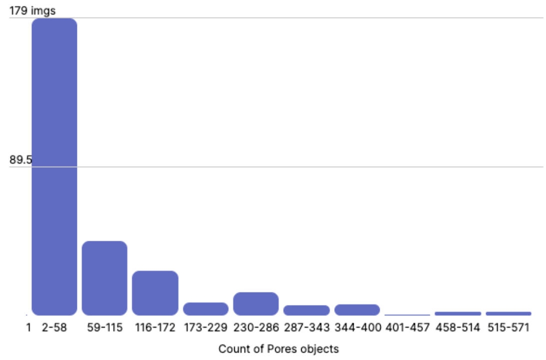

Figure 1.3: Histogram of Object Count by Image.

1.3. Annotation Heatmap

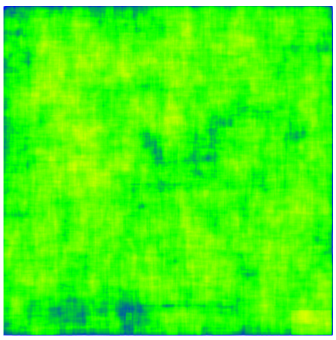

Figure 1.4: Heatmap illustrating the spatial distribution of annotated pores in the SEM image dataset, with darker regions denoting higher concentrations.

2. DEEP LEARNING MODEL

Convolutional Neural Networks (CNNs) are pivotal in image analysis, extracting hierarchical features for tasks like SEM image pore detection. However, had to go beyond using CNNs as building blocks. Instead, I strategically integrate YOLOv8x, a powerful object detection model designed for speed and accuracy. Choosing YOLOv8x for detection proves to be a judicious decision, as it exhibits superior performance with a mean average precision (mAP) of 53.9, striking a commendable balance between accuracy and computational efficiency compared to other YOLOv8 variants.

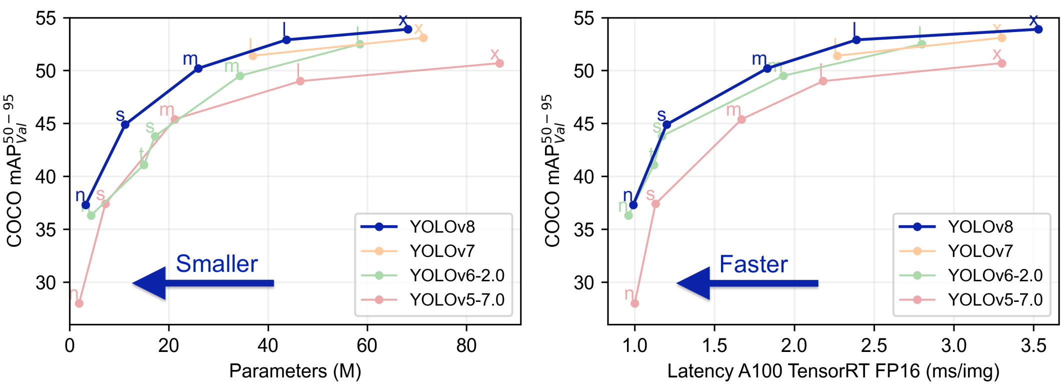

Figure 2.1: Comparison Plots of YOLO Versions

Table 2.1: Performance Comparison of YOLOv8 Models

Model	Size (pixels)	mAPval (%)	Params (M)	FLOPs (B)
YOLOv8n	640	37.3	3.2	8.7
YOLOv8s	640	44.9	11.2	28.6
YOLOv8m	640	50.2	25.9	78.9
YOLOv8l	640	52.9	43.7	165.2
YOLOv8x	640	53.9	68.2	257.8

2.1. Roboflow's Object Detection Model

Ultralytics, the creator and maintainer of YOLOv8, has partnered with Roboflow to be a recommended annotation and export tool for use in projects.

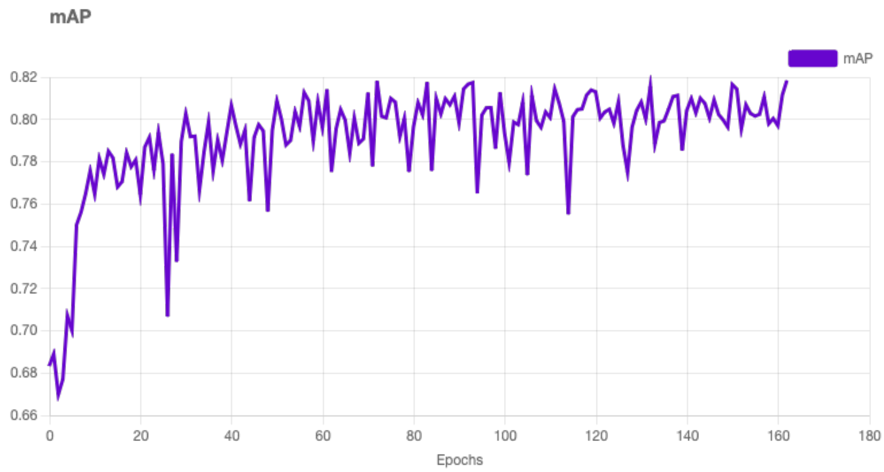

Figure 2.2: Mean Average Precision of Roboflow Annotation Model

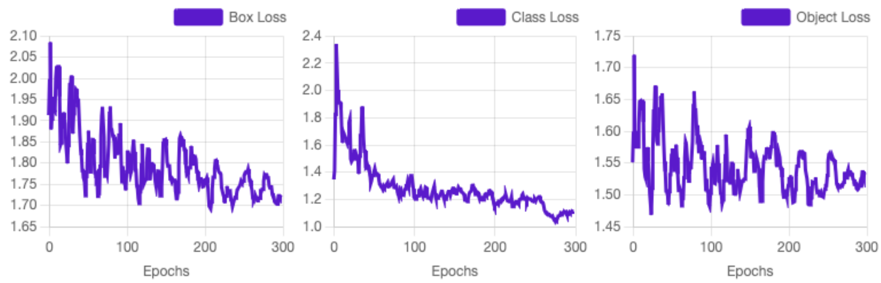

Figure 2.3: Box, Class and Object Losses of Roboflow Annotation Model

2.2. Pore Detection Model

Object Detection represents the evolutionary progression of Classification. This task involves identifying various classes within an image and precisely locating them, visually represented by Bounding Boxes. YOLOv8 models come pretrained on the extensive COCO dataset, a vast image dataset. This enables them to seamlessly perform Object Detection tasks without requiring additional training, showcasing their out-of-the-box efficacy.

My model training took place in the cloud-based environment of Google Colab, utilizing a meticulously curated dataset of SEM images with annotated pores. To achieve optimal performance for this specific task, I fine-tuned the pre-trained YOLOv8x model through 100 epochs, ensuring its adaptability to the intricate features and challenges present in my data. [3]

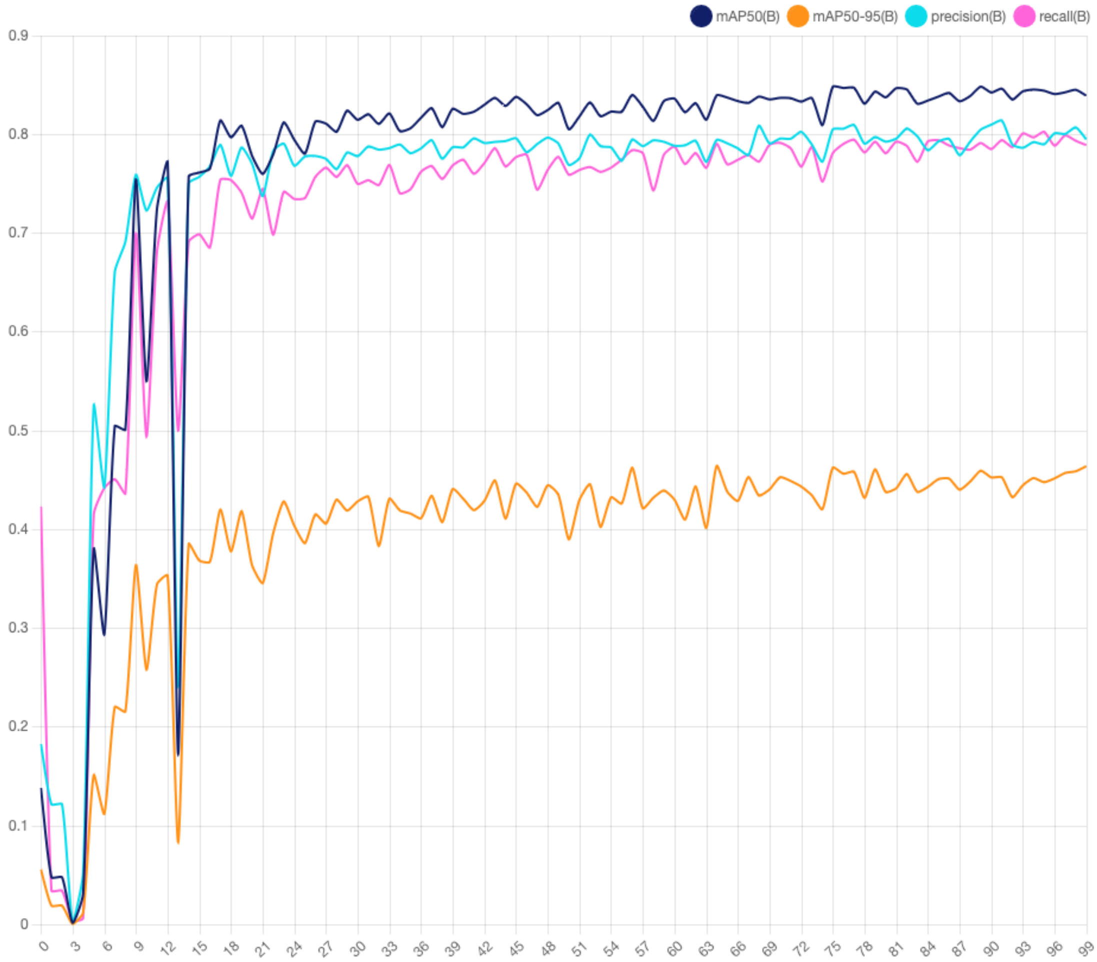

Figure 2.4: Model accuracy measured on validation set.

[4]

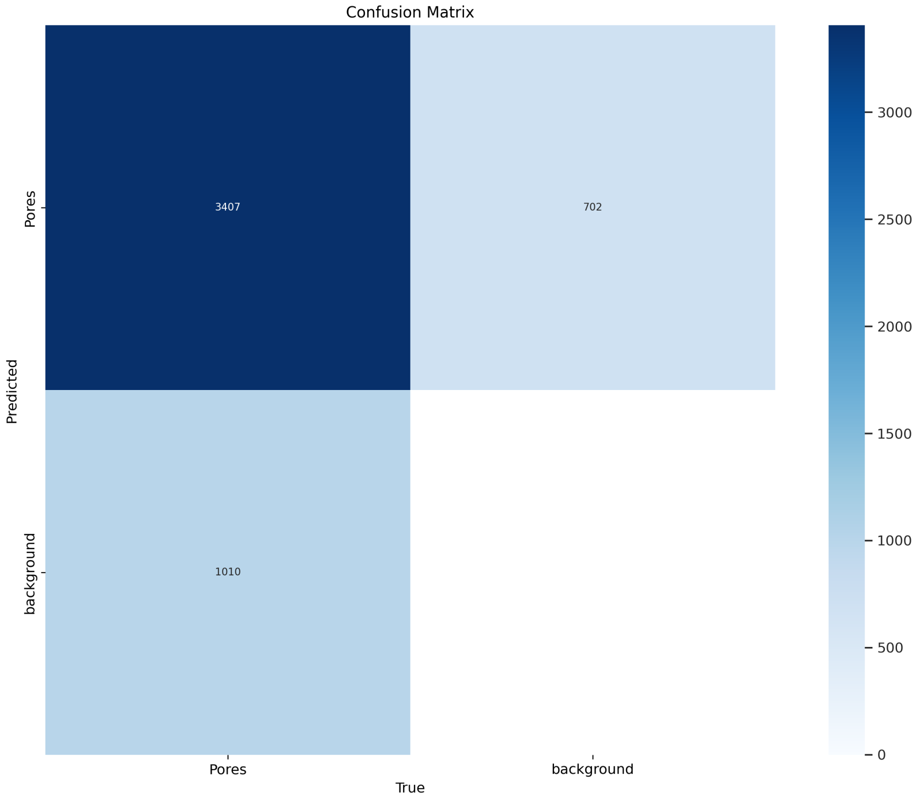

Figure 2.5: Confusion Pore Detection Model

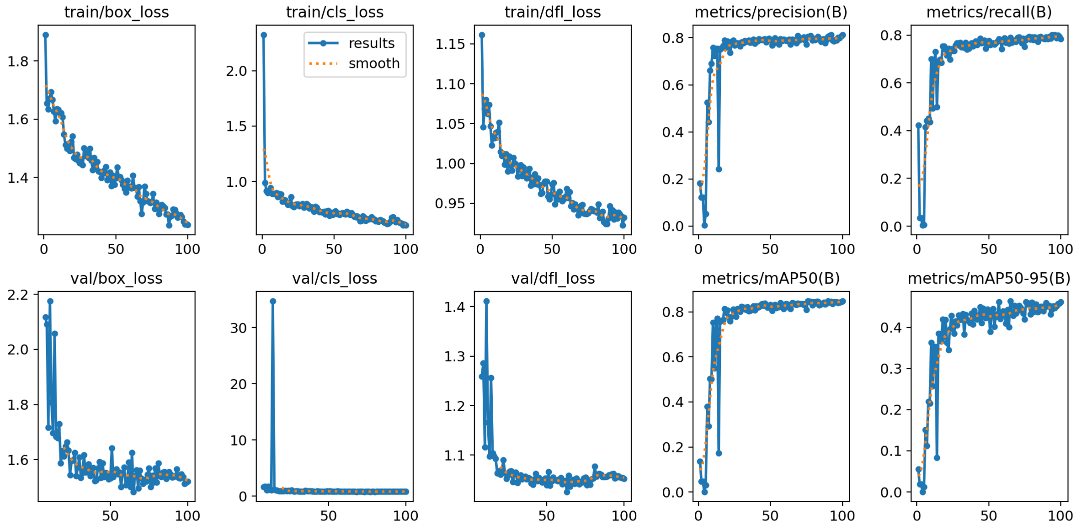

Figure 2.6: Results of training.

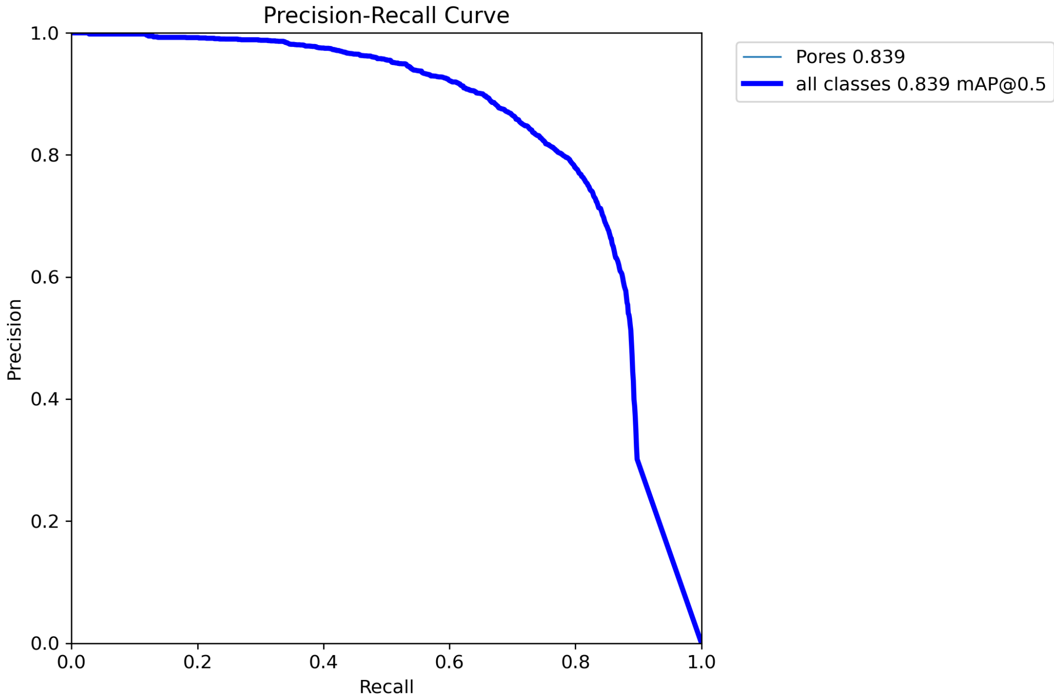

Figure 2.7: Precision-Recall Curve

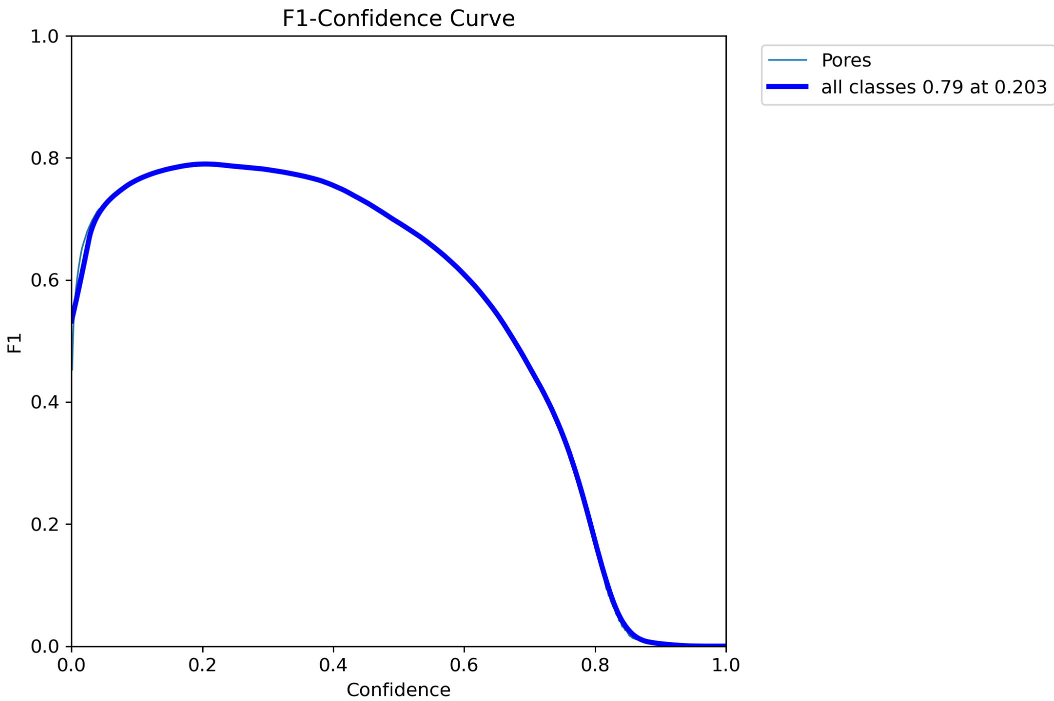

Figure 2.8: F1 Score Curve

2.3. GUI Development and Analysis

2.3.1. Porosity Analysis Algorithm

The Algorithm 1 shows the pseudo code of...

Algorithm 1 Porosity Aspect Ratio Classification

Require: Bounding boxes $bounding\_boxes$, Confidences $confidences$
Ensure: Weighted average aspect ratio $weighted\_avg\_aspect\_ratio$, Classification $classification$

```
Initialize empty lists aspect_ratios and weights
img ← Load and preprocess the image
Perform model inference using the YOLOv8 model
Extract bounding box information and confidence scores from the model output
Draw bounding boxes on the image
for each result in output[0].boxes do
    Extract bounding box information xyxy from result.xyxy
    Extract confidence information confidences from result.conf
    Convert xyxy tensor to a list and add to bounding_boxes
end for
Draw bounding boxes on the image using bounding_boxes
Calculate aspect ratio using the first bounding box in bounding_boxes
Add aspect ratio to aspect_ratios list
Add number of bounding boxes to weights list
Calculate weighted average aspect ratio using aspect_ratios and weights
Classify aspect ratio using the weighted average aspect ratio
Display the image with bounding boxes, aspect ratio, and classification
```

2.3.2. Calculation of Aspect Ratio

$$\text{Given a bounding box with coordinates } (x_1, y_1, x_2, y_2), \text{ its aspect ratio } AR = \frac{x_2 - x_1}{y_2 - y_1}. \tag{2.1}$$

$$\text{The weighted average aspect ratio } \bar{AR} = \frac{\sum_{i=1}^{n} AR_i \cdot w_i}{\sum_{i=1}^{n} w_i} \tag{2.2}$$

[5]

3. CONCLUSIONS

This study demonstrates the feasibility of pore detection and characterization in material surfaces using a custom-built dataset and a deep learning model. The model successfully identifies pores in scanning electron microscope (SEM) images, enabling further analysis of porosity parameters. Building upon existing research by Neslihan Tamgü on pore-material property relationships, this work focuses on microstructural visual features, particularly pore aspect ratio and its distribution. Preliminary findings suggest a correlation between aspect ratio percentages and permeability leakage rate values, offering insights into pore formation mechanisms. The developed deep learning application, equipped with a user interface, facilitates efficient porosity analysis, paving the way for further explorations in material characterization and research.

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CV

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Summary

Motivated computer engineering student about to graduate, problem solver, and excellent team player offering creative solutions on a wide range of platforms and digital systems from design to test. Currently gaining proficiency with advanced software concepts and a perspective on programming languages. Deep understanding of hardware concepts and aspiring to study Machine Learning. Experienced in developing web applications using Django and Javascript.

Experience

Full-Stack Developer Intern
Developed an attendee/workdays application for a fresh start, improving user experience with Django and Javascript. Implemented features and designed as needed.

Embedded Hardware/Software Intern
Performed tests and enhancements on a configurable UART library, presenting improvements through code modifications. Focused on a microcontroller-based project, configuring UART communication, and optimizing code structure. Utilized enum structures and class constructors to streamline UART configuration.

Unity Developer
Collaborated with the Environment Health and Safety unit to design and build new Virtual Reality applications to enhance emergency practices. Used Unity, Oculus Software, VR hardware, and C-sharp.

PowerApps Developer
Implemented PowerApps applications, integrating with other Microsoft Services such as Power Automate and Azure for tracking files and increasing productivity. Collaborated with the Human Resources department.

Skills

Programming Languages: C/C++, Java, Python, Verilog HDL, MIPS Assembly
Technologies: Unity, Microsoft Power Platforms, Docker, Kubernetes
Languages: English (fluent), Turkish (native), Russian (basic)

Projects

GTUHUKSAT-3A Cansat2019 (Developer of the Ground Control Station)
Real-time visualization and inscription of the telemetry using Python (Numpy, Matplotlib, Tkinter) and Anaconda. Design of the Flight Software in C, C++ for STM32 processor.

HydroMobil Shell Eco-Marathon17 (Developer of the I/O System)
Development of the touch screen (Nextion Touch Screen) and the whole system (Arduino Mega, C).

Volunteer Experience

AIESEC English Teacher
Volunteered as an English Teacher in Moscow, Russia, for adopted children from orphanages (June-August 2019).

APPENDICES

YouTube Demo

You can view a demonstration of the project on YouTube:
`https://youtu.be/Ff5Bj76P2LE`

GitHub Repository

You can find the source code and project materials on GitHub:
`https://github.com/ayseguldmrblk/SEM-Image-Analysis-Project`